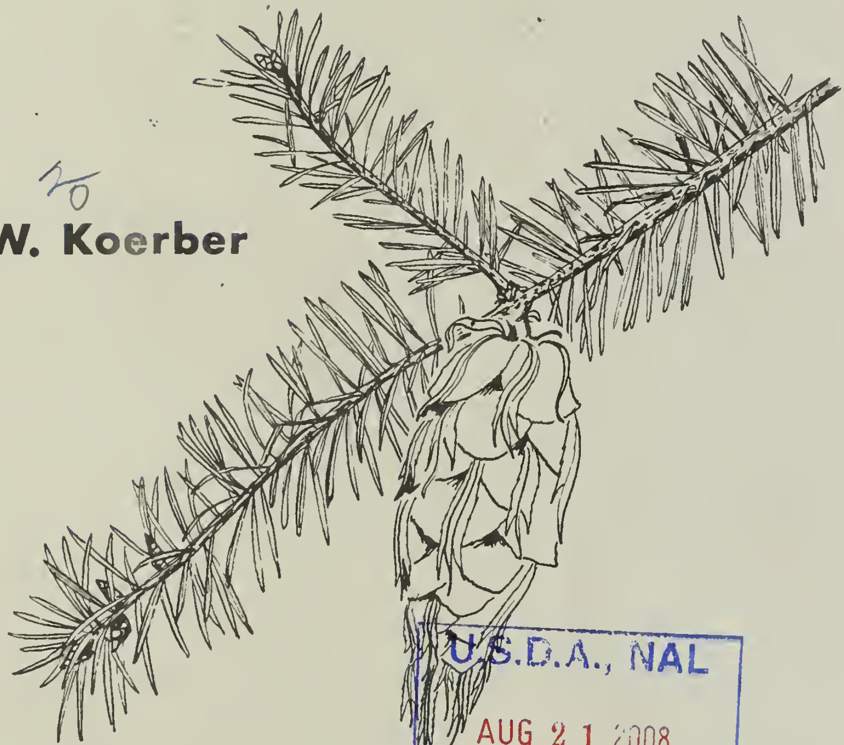
Technical Paper No. 45 - April 1960

INSECTS DESTRUCTIVE TO THE DOUGLAS-FIR SEED CROP IN CALIFORNIA .... a problem analysis



by Thomas W. Koerber

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FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE

SUMMARY

Since the 1940's, logging has increased rapidly in the Douglas-fir region of California. Much of the cutover area has failed to restock satisfactorily, mainly because of a shortage of seed. The seed loss caused by insects is especially serious. It occurs before the seed can be collected, and therefore hinders both natural regeneration and collection of seed for artificial regeneration. Preliminary investigations have revealed that four species of insects regularly destroy large quantities of Douglas-fir seed in California. This report reviews available information on these insects and suggests a research program aimed at reducing insect-caused damage to the Douglas-fir seed crop.

The general life histories and the habits of the insects are fairly well known. There are, however, some important gaps, particularly concerning the habits of the adult insects. There is also some uncertainty about the roles played by some of the species found in the cones. Very little is known as to the effect of biological and ecological factors on cone and seed insects and the interrelationships between the various insect species. The formulation of control methods, which is the ultimate objective of the research proposed in this report, will in large measure be dependent upon the development of methods of detecting and measuring insect populations at a given time. These sampling methods must necessarily be based upon biological data.

Therefore the needed research on insects destructive to the Douglas-fir seed crop in California has been divided into three priority classes:

Priority 1 - Studies on the identity, life history, habits, and ecology of the insects.

Priority 2 - The development of methods for determining population levels and related damage.

Priority 3 - The formulation of control procedures.

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INSECTS DESTRUCTIVE TO DOUGLAS-FIR SEED CROP IN CALIFORNIA--A PROBLEM ANALYSIS

By Thomas W. Koerber

Douglas-fir is one of the world's most valuable timber trees. In northern California and western Oregon and Washington, 22.6 million acres of commercial forest land are classified as Douglas-fir type. Douglas-fir occupies considerable additional area in southern British Columbia. It occurs in mixture with several forest types. The commercial harvest of Douglas-fir in the United States in 1952 amounted to 11.9 billion board feet. Although the bulk of this material came from the Pacific Northwest, 2.3 billion board feet were cut in California. By 1956 the California cut of Douglas-fir reached 2.4 billion board feet--41 percent of the timber cut in the state that year.

Douglas-fir frequently occurs in extensive closed stands of large, old trees. According to Isaac and Dimock (1958), smaller trees up to pole and small sawtimber size respond well to conservative thinning; the older trees, which have developed in a closed stand, are poorly adapted to radical release, such as that occasioned by very heavy thinning. When exposed, the long slender boles with short crowns are highly susceptible to damage from snowbreak, windfall, and sunscald. Consequently, Douglas-fir is usually harvested by clear-cutting in patches or strips. This method of cutting also facilitates the broadcast burning of slash which reduces the fire hazard and exposes a mineral seedbed.

If the clearcut strips or blocks receive a good seedfall and if other factors are favorable, dense stands of seedlings spring up on the cut-over areas. Because of fires and lack of seed, a large part of the cut-over land has failed to restock satisfactorily. As of 1952 there were 2,929,000 acres of unstocked commercial forest land in the Douglas-fir type in Washington, Oregon, and California (U. S. Forest Service, 1958), and 887,000 acres of commercial forest land were unstocked in northwestern California.[1]

Since 1952, cutting in northwestern California on national-forest land alone has averaged more than 22,000 acres per year,[2] probably adding a considerable amount to the unstocked area.

1/ Estimate from data in "Forest statistics for California," (U. S. Forest Service, 1954).

2/ Information provided by J. R. Berry, U. S. Forest Service Region 5, Division of Timber Management, San Francisco, Calif.

The factors which adversely affect the supply of seed are in large measure responsible for the failure of restocking of cutover Douglas-fir lands. To begin with, heavy seed crops are naturally irregular; they come at intervals of five to seven years. Complete seed crop failures occur at least as often as heavy seed crops, and light to medium crops occur most frequently (Isaac and Dimock, 1958). Squirrels, mice and birds eat large quantities of Douglas-fir seeds (Roy, 1958), and for unknown reasons much of the seed is often hollow.

Insects often exact a heavy toll. They are the first agents which act directly to reduce the amount of seed produced. Insects attack the cones as soon as they appear on the trees and complete their destructive efforts before the seed ripens. They may also attack the seed in storage. The most destructive insects feed in the cones during larval stages. Some seed is eaten by the larvae, and additional seed is trapped in the cones by deformities and galls caused by the insects.

Because insects damage the seed before it falls or can be collected, they reduce the chances for natural regeneration and for nursery production of seedlings for artificial regeneration. Less land can be planted, and a monetary loss results when unstocked areas are kept out of production.

Adequate data on the amount of seed destroyed by insects are difficult to obtain, but the existing estimates leave little doubt that these pests destroy large amounts of seed. According to Stevens (1959), a range of 17 to 73 percent of the Douglas-fir cone crop in northwestern California was infested by cone moths (chiefly Barbara colfaxiana (Kearf.) and Dioryctria abietella D&S.) in the years 1956 to 1958. In addition 0.4 to 7.1 percent of the seed was destroyed by seed chalcids (Megastigmus spermotrophus Wachtl) during this period. Data collected by D. F. Roy, which are reported by Stevens, show that from 0.7 to 21 percent of the seed caught in seed traps in northwestern California from 1954 to 1957 was infested by seed chalcids. In British Columbia, 32 percent of the Douglas-fir cones were found to be infested by Barbara colfaxiana and 33 percent by Contarinia oregonensis Foote (Hedlin, 1958). The larvae of Contarinia oregonensis destroyed nearly 50 percent of the 1957 Douglas-fir seed crop in certain areas of the Pacific Northwest (Johnson and Heikkenen, 1958).

In 1958 the U. S. Forest Service collected 960 sacks of Douglas-fir cones from a moderate crop in northern California. These cones were expected to yield 1,440 pounds of seed. Although heavily infested cones were not harvested, the actual seed yield was only 667 pounds. The reduction amounted to a loss of $11,600.[3]

3/ Data furnished by J. L. Averell, U. S. Forest Service, Region 5, Division of Timber Management, San Francisco, Calif.

Currently the regeneration program on the national forests of California could use 500 pounds of Douglas-fir seed per year. As the regeneration program is enlarged, the demand for Douglas-fir seed is expected to increase to 1,000 pounds per year. This quantity would be used to produce 6 to 10 million seedlings annually for planting stock and to reforest large areas by aerial seeding.[4]

Generally speaking, in years when the cone crop is heavy, a relatively small percentage of the seed is destroyed by insects; in years when the crop is small, insects take a larger portion. Therefore insects are likely to present a much more serious threat to seed production in years of small to moderate cone crops than in years when cones are abundant.

To compound the problem, the establishment of Douglas-fir becomes increasingly difficult as time passes after an area has been logged off. Isaac (1943) lists several variables, including soil type and aspect, which influence the establishment of seedlings. Soil surface temperatures above 125°F. are fatal to very young seedlings. Spring frosts, summer drought, winter frost heaving, diseases, insects, and animals all take their toll, so that only a very small percentage of the germinated seed produces established seedlings. Regeneration is increasingly difficult from north to south because of a progressive decrease in precipitation and increase in intensity of insolation. Throughout the Douglas-fir region brush and herbaceous vegetation rapidly invade the cutover areas, and although some shade is beneficial, Douglas-fir reproduction has little or no chance of successful establishment in anything less than 20 percent of full overhead light, even where there is no root competition. In northern California, studies by D. F. Roy indicate that because of the rapidly developing brush competition, reproduction must become established within three years after logging to regenerate Douglas-fir stands (U. S. Forest Service, 1958a).

Research on several regeneration problems other than insect damage has been started in recent years. It includes studies on improved seed production (Allen, 1958), protection of seed from birds and mammals (Spencer and Kverno, 1952), and the effect of competing vegetation on regeneration of conifers (Lavender, 1958).

Since the destruction of Douglas-fir seed by insects is a major factor in reducing the supply of seed, research on seed-destroying insects can undoubtedly do much to alleviate regeneration

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4/ Information obtained from J. Buck, U. S. Forest Service, Region 5, Division of Timber Management, San Francisco, Calif.

problems. It may:

(1) Help get better natural regeneration.

(2) Improve seed crops from both natural stands and special seed production areas.

(3) Provide information of value to forest geneticists engaged in the breeding of Douglas-fir. Investigations pointed toward these general objectives have been started for conifer timber in several areas. For Douglas-fir, studies are in progress at the Canadian Forest Biology laboratory at Victoria, B. C. and the Weyerhaeuser Company Research Center at Centralia, Washington. Preliminary research on the cone and seed insects of Douglas-fir in California was started in the North Coast Range in 1957. This report summarizes that work. It analyzes the types of problems related to insect damage to the Douglas-fir seed crop in California. It summarizes available information, and lists research needs and their priorities.

PROBLEMS FOR RESEARCH

Research problems associated with cone and seed insects can be divided into six groups. The aspects of the problem which will be considered are:

(1) The identity of the insects found in the cones and seeds and staminate strobili.

(2) The nature and extent of damage caused by each species.

(3) The life history and habits of the insects which reduce seed production.

(4) The effect of ecological factors, such as weather conditions, parasites, and predators on the insects.

(5) The development of sampling methods for cone and seed insect populations.

(6) The formulation of control practices.

The division is arbitrary, however; the different categories are closely interrelated and a single experiment or observation may yield data which will apply to several divisions.

IDENTITY is a matter of primary importance. The name and description of an insect provide the key to all of the published information on the insect and also reveal the insect's position in the phylogenetic classification system. With this knowledge, we can

draw from information on better known, closely related species for clues to the probable life history, habits, ecology, and perhaps even the control of the insect. The extent to which this can be done depends on what is known about the similarities and differences between related species. Preliminary investigations have revealed the need for taxonomic studies on some of the insects involved. Although these studies are a part of the identity problem, they generally can best be undertaken by specialists in insect taxonomy. The Station entomologists can help to solve taxonomic problems by obtaining specimens and biological data for the taxonomic experts.

NATURE AND EXTENT OF DAMAGE is the next problem. We need to know the damage caused by each insect species associated with the cones and seeds on the tree and in storage. This "role" of each species must be associated with identified specimens so that the relative importance of each species and its economic significance can be ascertained. This information is needed to separate the destructive pests from the parasites, predators, and incidental residents of the cones.

LIFE HISTORIES AND HABITS, and the ecological factors which affect them, must be known in detail. This is vital information for determining the type of control practices to be used and the timing of control operations.

CLIMATIC FACTORS also affect control operations. Knowledge of climatic effects may reveal whether the microclimate of a seed production area can be altered in such a way as to reduce insect populations. Perhaps Douglas-fir will grow and produce seed in places which have a natural climate unfavorable to cone and seed insects. Obviously information of this type would be of much value.

NATURAL ENEMIES of several kinds are known to attack cone and seed insects. Knowledge of the habits and life histories of insect parasites and predators and the effect of each upon host populations, is needed to determine how effective these organisms are as control agents. It may be possible to develop ways of encouraging parasites and predators so as to prevent damage. Moreover, if cone and seed insects must be controlled with chemicals, knowledge of the habits of the parasites and predators will be useful to minimize the harm to them from sprays. Diseases may also be an important natural control factor. Research should show whether cone and seed insects harbor disease organisms, their effect on the host insect population, and the possible uses of pathogenic organisms as control agents.

INTERRELATIONSHIPS between various species of cone and seed insects should get special attention. When the supply of insect food

is limited, as in Douglas-fir cones, one or two of the most successful insect species may suppress others that attack the same host material to very low population levels. If the dominant insects are eliminated by natural means, through spraying, or other practices, the previously suppressed species may suddenly multiply and present serious control problems.

HOST SPECIFICITY studies should determine if some of the insects that attack Douglas-fir may have alternate host trees. In sampling and control it would be most important to take these additional sources of infestation into account.

RESISTANCE OF THE HOST TREES to attack by cone and seed insects should be investigated. It is entirely possible that individual Douglas-fir trees differ in susceptibility to attack. It would indeed be fortunate if trees having both good growth characteristics and high resistance to cone and seed insects could be propagated as a seed source.

SAMPLING METHODS must be devised before any large scale control operations are started. They provide means for detecting the presence and measuring the level of cone and seed insect populations. Sampling methods are also needed to obtain information on the population dynamics of the important insects. A technique for detecting and identifying the insects in their very early stages is needed not only to determine the prospects of damage early in the season, but also to time control operations properly. Sampling methods are also required to measure the effectiveness of control work and to determine the trends in insect abundance. The methods would be useful even where no control measures are available: they would provide data for predicting the amount of damage to the seed crop soon enough to help plan seed collection and nursery and planting operations.

CONTROL MEASURES are the ultimate objective of research on Douglas-fir cone and seed insects. Several general types of control measures can be considered for use against these insects. The most obvious is to apply insecticidal materials. Research should test various insecticides for their toxicity to cone and seed insects, and determine the rate, time, and method of application which give the best results. Cultural practices may aid control by reducing the amount of damage caused by cone and seed insects. For example, gathering and burning all the infested cones in a seed production area would help to reduce insect damage in the following year. Data obtained in biological and ecological investigations may provide clues to possible cultural control measures. Such data may also lead to the development of procedures for using parasites, predators, or disease organisms for control purposes. All possibilities for developing effective control methods should be thoroughly explored. Each control method has inherent advantages and disadvantages which must be finally considered to determine which method or combination

of methods will best insure a dependable supply of high quality Douglas-fir seed.

RESULTS OF PAST STUDIES

The earliest published report on the insects with which we are concerned came from Scotland-- a 13-page article on *Megastigmus spermotrophus* (MacDougal, 1906). Evidently this seed chalcid had found its way to Scotland in infested seed and had attacked the cones of Douglas-fir imported from the United States or Canada. At about the same time R. A. Cooley (1908) studied the cone and seed insects of Douglas-fir in Montana and published a brief paper on the "Douglas-spruce" cone moth. 5/

In 1913 in Oregon, J. M. Miller and J. E. Patterson, at the suggestion of A. D. Hopkins, started studies on cone and seed insects. Two short papers on *Megastigmus spermotrophus* were published by Miller (1914, 1916). In 1916 Miller and Patterson compiled a comprehensive report on biology and economic importance of *Barbara colfaxiana*, and though never published, this report served as a source of much of the information on this moth given by Keen (1958). The work on cone and seed insects by these investigators was discontinued in 1917.

During the next 25 years very little research other than taxonomic studies was done on Douglas-fir cone and seed insects. In 1940 and 1941 K. Graham and M. L. Prebble conducted an extensive and detailed study of insects affecting the cones and seeds of Douglas-fir but the data were never published.

Since 1950 there has been a marked revival of interest in this group of insects. In 1952 D. N. Radcliffe published three papers on *Barbara colfaxiana* on the basis of data gathered in British Columbia in 1950 and 1951. In 1953 the Weyerhaeuser Timber Company started research on the biology and control of Douglas-fir cone and seed insects. A report by Rudinsky (1955) and another by Johnson and Heikkenen (1958) have resulted so far.

In California, the Forest Service started damage surveys of Douglas-fir cones in 1954 and has conducted surveys annually since then (Stevens, 1959). Preliminary research on Douglas-fir cone and

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5/ Keen (1958) states, "Although this species was not named by W. D. Kearfoot until 1907, it apparently was first covered by R. A. Cooley in Montana in the spring of 1900. Cooley prepared a bulletin on "The Douglas-spruce cone moth" in 1908 from his studies on this species. In this bulletin the species was identified as *Cydia pseudotsugana* Kearf. The writer is reasonably certain that the species was wrongly identified and that Cooley's bulletin is the first dealing with the Douglas-fir cone moth *Barbara colfaxiana* vars."

seed insects in California was started in 1957. Observations made by the writer as part of this preliminary research, as well as published and unpublished data of other workers, have been drawn upon for this summary of available information on Douglas-fir cone and seed insects.

The literature on Douglas-fir cone and seed insects is sparse and widely scattered. Most of it has been summarized by Keen (1958). He lists 63 species of insects which have been found in Douglas-fir cones. Seventeen are believed to be in some measure damaging to the cones. The roles played by 13 of the species are uncertain; 33 are parasites and predators.

A thorough study of the literature supplemented by current work at this Station reveals that only three of the insect species listed by Keen regularly cause significant amounts of damage to Douglas-fir cones and seeds in California: *Barbara colfaxiana*, *Dioryctria abietella*, and *Megastigmus spermotrophus*.

Recent research by Johnson and Heikkenen (1958) indicates that *Contarinia oregonensis* Foote, previously considered an unimportant species, also causes serious losses of Douglas-fir seed in Oregon and Washington. Midges reared from Douglas-fir cones collected in northern California showing damage similar to that described by Johnson have been identified by R. H. Foote [6] as *Contarinia* sp. near *oregonensis*. The factors which place these four species far above other species in destructiveness are not known. It is entirely possible that under the proper circumstances one or more of the so-called unimportant species could cause serious damage to Douglas-fir cones or seeds.

Table 1 lists insects which have been associated with Douglas-fir cones and seeds; table 2, those whose role is uncertain.

BIOLOGY AND ECOLOGY OF PRINCIPAL SPECIES

Barbara colfaxiana (Kearf.)

Although some biological and ecological information is available on all of the common cone and seed insects, *Barbara colfaxiana* has been the species most widely and intensively investigated. The information presented here is a summary of data from Miller and Patterson (1916), Graham and Prebble (1941), Radcliffe (1951), Rudinsky (1955), Johnson [7], and preliminary studies at this Station.

6/ Insect Identification and Parasite Introduction Laboratories, Entomology Research Division, Agricultural Research Service, U. S. Dept. of Agriculture.

7/ Unpublished data from recent work by N. E. Johnson at the Weyerhaeuser Company research laboratory, Centralia, Washington.

The moths of Barbara colfaxiana appear early in the spring, shortly before the Douglas-fir cone buds open. This occurs in mid-April at lower elevations in northern California. The eggs are deposited on the bracts of the new cones. Oviposition continues for 3 to 5 weeks, apparently because of continued emergence of adult moths. Thus far no observations show a preference by this insect for any particular level or exposure of the tree crown. However, exposed cones are more heavily attacked than those heavily shaded by foliage. There are no significant differences between the numbers of eggs deposited on the basal, middle, or terminal third of a cone. The eggs hatch 15 to 20 days after oviposition.

The newly emerged larvae leave the bract and bore into the cone tissue between two scales, or between a scale and bract. A flow of pitch accompanies about a third of the attacks, but the pitch is not particularly detrimental to the further development of the larvae. The larvae bore toward the center of the cone, reaching the seed-bearing region by the end of May or early June. They tend to remain in the center of the cone--feeding indiscriminately on scales, bracts, and seeds. Pitch and frass accumulate in the irregular cavities excavated by the feeding larvae. In severely damaged cones the terminal portion may die and turn yellow in the early part of July. The larvae reach maturity by the end of July.

Pupation occurs within the cone in a papery cocoon encased in pitch. The insects remain in the pupal stage (figure 1) from late July until the following April. A significant portion of the pupae, often 10 to 20 percent, do not transform to adults after the first winter. These pupae pass a second winter before transforming to adults, and an additional small percentage may pass three winters before becoming adults. Little is know about the ecological factors which affect the population levels of Barbara colfaxiana. At least 15 species of insects are known to be parasites or predators of this species, but none has been reported to be an effective control agent. Winter mortality of the pupal stage is said to be higher in cones remaining on the trees than in cones which fall to the ground, and also higher on dry sites than on wet sites.

Apparently the most important factor controlling the size and fluctuation of the population is the supply of Douglas-fir cones. However, Barbara colfaxiana is less severely affected by a small crop than other cone and seed insects because it is a more successful competitor for the limited food supply. The portion of the population which does not transform to adults after the first winter in the pupal stage serves to carry the insect through years when the cone crop fails.

Dioryctria abietella (D. & S.)

Dioryctria abietella has not been intensively studied on Douglas-fir. What has been done indicates that this species has a wide range of habits. Furthermore, recent taxonomic studies by Munroe (1959)

Figure 1.--Douglas-fir cone cut open to show damage caused by the larva of Barbara colfaxiana (Kearf.). Note pupa in cocoon near cone axis.

Figure 2.--Douglas-fir cone showing damage caused by the larva of Dioryctria abietella (D. & S.).

indicate that the biological data presented here for Dioryctria abietella may actually concern two or three species rather than only one.

This moth is reported to feed in the cones of slash and longleaf pines in Florida (Ebel and Merkel, 1957), in the cones of red pine in Ontario (Lyons, 1957), in cones of pine, spruce, true firs, and Douglas-fir in British Columbia (Ross, 1958), and in Douglas-fir cones in California (Stevens, 1959). The larvae are also reported to be shoot borers in pine, miners in the cambium of smooth bark of pines and Douglas-fir, and miners in fungus galls on pines. They are said to feed occasionally on foliage and buds.

The following information on the habits and life history of Dioryctria abietella is based upon data reported by Keen (1958) from Ashland, Oregon, and fragmentary data recently collected in northern California by the writer.

Some eggs probably are deposited by moths reaching the adult stage in October or early November. These eggs are thought to hatch in early spring. More eggs are produced by another group of moths which appear in April or early May. These eggs hatch after a short time. Some eggs are deposited on young Douglas-fir cones, but most are deposited in some other undetermined location.

Small larvae appear on the cones by the end of May. They bore through the cones and feed indiscriminately on scales, bracts, and seeds (figure 2). The larvae of Dioryctria abietella usually do not bore as deeply into the cones as do the larvae of Barbara colfaxiana. As a result less seed is destroyed by Dioryctria abietella.

As the cones ripen in the autumn, the larvae leave them and spin their cocoons on the ground. Some of the larvae pupate immediately and emerge as adults and lay eggs in October and November. The remainder spend the winter as prepupal larvae in their cocoons on the ground, waiting until spring to complete their development. A small proportion of the larvae may not reach maturity by the end of the summer, but survive the winter and complete development the following spring.

There is almost no information on ecological factors which might affect this species. Only six species of parasites and predators are known to attack it in western North American. Its wide distribution might be taken to indicate a tolerance for a wide range of climatic conditions. Because of its variable feeding habits, population levels of Dioryctria abietella are probably relatively independent of the supply of cones and thus are not likely to suffer from competition for food supplies.

Megastigmus spermotrophus Wachtl

Megastigmus spermotrophus is a fairly well know insect, having been studied in both North America and Europe. This species almost certainly feeds only on the seeds of Douglas-fir. It is found throughout the North American range of this host, and has been introduced via infested seeds into Europe and New Zealand.

The life history and habits of Megastigmus spermotrophus have been reported in detail (Hussey, 1954). Oviposition takes place in late April and throughout May at the time when the new Douglas-fir cones are 2 to 3 weeks old. The adult female, a small wasp, has a long ovipositor which is inserted through the cone scale to deposit the egg in a developing seed. Normally only one egg per seed is deposited, but if more than one is deposited only one larvae will reach maturity.

The egg hatches in 3 to 5 days, producing a larvae which consumes the interior of the seed. The larva matures in 6 to 8 weeks, each larva remaining in an individual seed (fig. 3). The mature larvae pass the winter in the hollow seed coat. There pupation takes place in early spring after most of the seeds have fallen to the ground. Subsequently the adults emerge in time to attack the new cone crop. Many of the larvae, possibly 15 percent, do not pupate after the first winter but remain in the seed for another year or possibly longer.

Nothing is known about the effect of climatic factors on the population levels of Megastigmus spermotrophus. Larvae overwintering in the seeds may be vulnerable to extreme temperatures or other climatic conditions. It also seems probable that, as with some of the other insects, the population level could be indirectly controlled by the effect of climatic factors on the quantity and quality of Douglas-fir cones.

The position of the larvae in the seeds deep inside the cones protects them from most parasites and predators. Three species of chalcid wasps reported by Hussey (1955) are the only recorded parasites of Megastigmus spermotrophus. No predatory insects are known to attack the egg, larval, or pupal stages, all of which occur inside the seeds. Hussey (1956) indicates that in Scotland seed-eating rodents destroy the larvae in infested seed on the ground, but no such attacks have been reported in the United States. In California preliminary observations indicate that in years when the cone crop is small and infestation rates by other cone and seed insects are high, Megastigmus spermotrophus fares badly in the competition for the limited food supply. The other insects, especially Barbara colfaxiana, may destroy nearly all of the Douglas-fir seed along with the Megastigmus larvae they contain. The extent to which the destruction of seeds by other insects reduces the population of Megastigmus spermotrophus

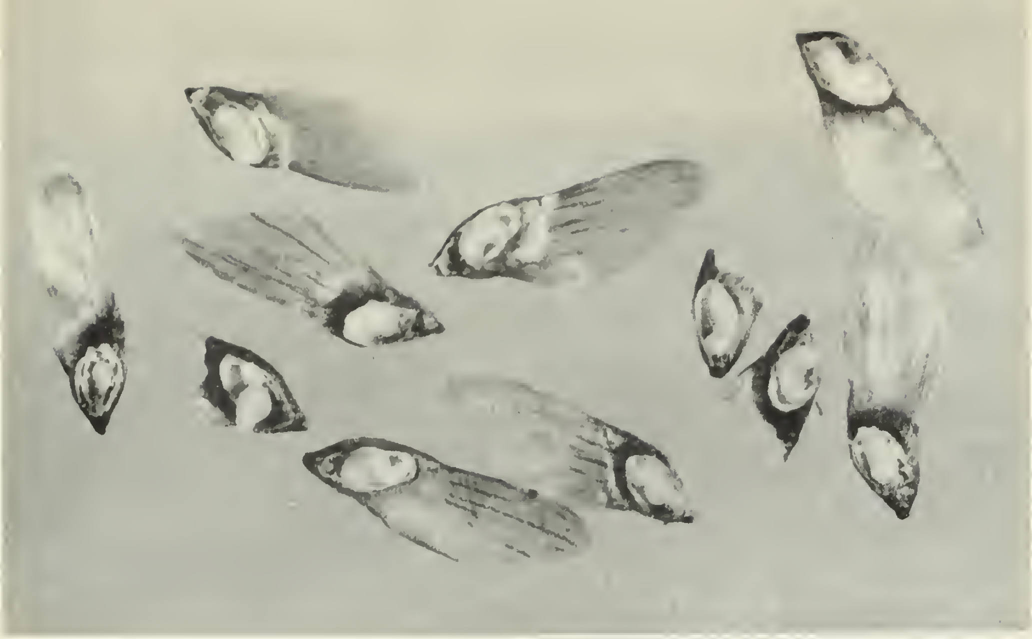

Figure 3.--Douglas-fir seeds cut open to show the larvae of Megastigmus spermotrophus Wachtl.

Figure 4.--Douglas-fir seed deformed and fused to cone scales by the galls of Contarinia sp. near oregonensis. Note larva in gall where seed has been removed (arrow).

is not known. In Europe, where Megastigmus spermotrophus has few competitors, it regularly destroys a large percentage of the seed crop. Though this may be attributed to the lack of competition, other factors may also be important.

Contarinia oregonensis Foote

Contarinia oregonensis was first described by Foote (1956). Early damage reports indicated that although various species of midges were present in the cones they were not believed to cause a significant amount of damage. But damage by Contarinia oregonensis has been reported to exceed that by all other cone-infesting insects in western Washington (Johnson and Heikkenen, 1958). Recent studies in northern California by members of this Station indicate that a species of midge very similar to C. oregonensis is capable of destroying the entire Douglas-fir seed crop over a considerable area.

According to Johnson and Heikkenen (1958) the eggs of Contarinia oregonensis are deposited betweeen the developing cone scales during the brief period when the cones are open to receive pollen. When the eggs hatch, the larvae bore into the cone tissue and begin feeding, usually on the developing cone scales near the seed. By the end of May the larvae become encased in galls in the cone tissue. In heavy infestations the galls may completely destroy or displace the seed. In lighter infestations they do not destroy the seed; however, the seed coat or wing is fused to the gall so that the seed will not fall from the cone when ripe (fig. 4). The mature larvae leave the cones during the fall and winter and drop to the ground to pupate. Upon reaching the ground, the larvae form thin cocoons in the litter. Pupation takes place in early spring, the adults emerging from the cocoons in time to deposit eggs on the new cones.

No information is available on the climatic factors which might affect Contarinia oregonensis, but larvae overwintering in the duff are likely to suffer heavy mortality from unfavorable temperature and moisture. Since the cones of Douglas-fir are the only recorded hosts, it is assumed that factors which affect the abundance of Douglas-fir cones would affect the insect by limiting its food supply.

The larvae of Contarinia oregonensis are sometimes heavily parasitized by a chalcid wasp of the genus Torymus. Several other parasites and at least one predator are known to attack the larvae in the cones. Nothing is known about parasites and predators which might attack the larvae after they leave the cones. Many predaceous insects and mites inhabit the duff where the larvae spend the winter and spring. Conditions in this environment are also likely to be favorable for the development of disease organisms. The feeding of other insects, especially Barbara colfaxiana, in the cones, may reduce the midge population to a considerable extent. However, enormous numbers of larvae can mature in a single cone. This capability, along with the great reproductive capacity characteristic of insects, would tend to counteract the effects of competition for food.

SAMPLING METHODS

The sampling method used to obtain data on the prevalence or amount of damage done by cone and seed insects largely determines the degree of reliability and usefulness of the results. It is desirable to have a sampling method which will yield a reliable estimate of both the number and kind of insects in the population and the amount of damage they have caused. It is even more desirable to have methods which will give an estimate early in the season of the amount of damage to be expected by the time the cones mature. The ideal sampling method would also give an estimate of the prevalence of parasites, predators, and other mortality factors which might be helpful in predicting population trends.

Past researchers on cone and seed insects have necessarily used some type of survey method to gather data on damage. Miller and Patterson (1916) evidently dissected samples of mature cones. For their cone-moth data they determined the percent of cones infested, the percent of the seed destroyed, and the number of larvae per cone. For their data on Megastigmus they took seed samples and cut the seeds to determine the percent infested. Graham and Prebble (1941) dissected cones throughout the summer and recorded the condition of each ovule and scale. They determined the average number of sound and damaged scales and ovules per cone in each sample. Damage by midges, seed chalcids, and moth larvae was recorded separately, and various types of damage and abnormalities not caused by insects were also recorded. In the final compilation the damage ascribed to the various insect species could be compared on the basis of the average number of ovules per cone damaged by each species.

Radcliffe (1951) used several sampling systems. Immature cones were collected and dissected to determine the position of attack by Barbara colfaxiana larvae on the cones. Random samples of mature cones were taken from selected trees and divided by visual inspection into infested and uninfested subsamples. The cones were dissected to determine the number of larvae and pupae present and the number of seeds destroyed per cone. The seeds from both the uninfested and infested cone samples were extracted, cleaned, and subjected to cutting and germination tests. Similar tests were conducted using samples of cones taken from drying bins at the seed extraction plant. These samples were graded into discrete groups based on percent of cones infested, i.e. 0-20, 21-40, etc. The results of these tests were expressed as percent seed lost in cones having one, two, or three larvae per cone, or percent lost in cone samples 0-20 percent infested, 21-40 percent infested, etc. Cone samples were collected from various habitats in the spring, and the overwinter mortality and rate of parasitism of the cone moth pupae were determined.

Rudinsky (1955) collected random samples of cones from selected trees throughout the summer. The cones were sliced in

half longitudinally and the number of sound seeds and the number of damaged seeds on the cut surface were counted. The number and kind of insects in the cones were also recorded. The data were expressed as percentage of cones infested by each of the commonly destructive species of insects. No quantitative estimate of seed loss was given in the final publication.

Hall (1955) sampled cones from freshly felled trees at weekly intervals. The damage found was presented as percent of seed destroyed.

Stevens (1957) made visual examinations of samples of mature cones to determine the percent infestation by cone moths. Samples of seed were extracted from the cones and cut to determine the percentage destroyed by seed chalcids. Seeds found to be hollow but having no clear indication of insect damage were reported separately.

Johnson and Heikkenen (1958) collected random samples of mature cones from selected areas. Half of the cones were examined for midge damage by the longitudinal slice method used by Rudinsky (1955), and half by total dissection. The data on midge damage obtained by the two methods were compared statistically, and no significant difference was found. Thereafter the amount of damage caused by cone midges was estimated by the longitudinal slice method and expressed as percent of seed damaged and percent of all insect damage. Johnson has continued to use this method in more recent work. Hedlin (1958) collected cones at random at intervals during the summer from all the cone-bearing trees on selected 1/4-acre plots. The cones were dissected, and the species of insects found and the amount of damage caused by each species were recorded. The data were expressed as average number of ovules per cone destroyed and percent cones infested by _Barbara colfaxiana_ and by gall midges.

CONTROL

Efforts to control cone and seed insects and research on control methods have leaned heavily toward application of chemical insecticides. Although some thought has been given to other control procedures, none of the researchers working on cone and seed insects has investigated the practicability or effectiveness of alternative methods of control. Consequently the possible use of parasites, predators, and diseases or the manipulation of microclimatic factors remain virgin fields for investigation. At present there is no basis for predicting that investigations of alternative methods will yield an effective control. But the inherent long-term effectiveness of cultural and biological methods, coupled with the disadvantages of chemical control, make the search for such methods seem well worthwhile. Many parasites and predators are known to attack cone and seed insects (table 3). However, detailed information on their life histories and habits must be obtained before experiments can be conducted on the use of parasites and predators.

The first attempt at insecticidal control of the insect complex attacking Douglas-fir cones was made by Rudinsky (1955) at the Clemons Tree Farm of the Weyerhaeuser Company. Four groups of trees, each containing ten trees, were sprayed so that one group was sprayed four times, one group three times, one group two times and the last group once. The toxicant was DDT applied as a $2\frac{1}{2}$ percent water emulsion by ground equipment at the rate of 2 gallons per tree. The first spray was applied on May 7, about 2 weeks after the reproductive buds opened. The remaining sprays were applied on May 21, June 18, and July 23. The effect of the spray was evaluated by dissecting the cones and comparing the percentage of sprayed and unsprayed cones infested by cone moths, cone midges, and seed chalcids. The infestation rates of the check cones were not large enough to warrant definite conclusions, but there was an indication that the spray application made 2 weeks after the reproductive buds opened protected the cones from attack by cone moths and seed chalcids. The number of midge larvae was considerably reduced but would need to be brought lower to get satisfactory protection from midge damage.

Spray tests were resumed in 1958 by N. E. Johnson with emulsions of ten insecticides. 8/ A hand sprayer was used to apply insecticide to the point of runoff on selected branches of two cone-bearing Douglas-fir trees. The materials and concentrations used were: Guthion, malathion, sytam (OMPA), Thimet, and Trithion at 0.2 and 0.1 percent; lindane, dieldrin and Sevin 0.2 and 0.4 percent; and rotenone 2.5 and 5.0 percent. Effectiveness of these applications was evaluated by comparing cone moth and cone midge damage in sprayed and unsprayed cones from the same tree. Guthion and Thimet gave the best control of cone moths; Buthion and Sevin were most effective against the cone midge. The best treatments resulted in only about 2-fold increase in the number of sound seed per cone even though Guthion gave 100 percent control of the cone moths. Lindane, which gave the best results in tests against cone insects in the Southeast, gave virtually no control of either cone moths or the cone midge in Johnson's experiments.

Studies in the Southeast are especially relevant because one of the most important insects involved was Dioryctria abietella. At Gulfport, Mississippi, Coyne (1954) conducted experiments to find methods of protecting the cones of slash and longleaf pine from insect damage. The most effective treatment consisted of four applications at bimonthly intervals, starting in March, of 1/2-percent benzene hexachloride water emulsion applied at the rate of three gallons per tree by ground equipment. As a result of this treatment, loss of cones due

8/ Weyerhaeuser Company, Forestry Research Center, Centralia, Wash. unpublished data.

to insect damage was reduced from 74 percent on untreated trees to 30 percent on treated trees.

In research on insecticides, Ebel and Merkel (1957) determined that six monthly applications of lindane as a 1/2-percent water emulsion gave better control than the same dosage of DDT. In 1958 they conducted laboratory screening tests by using deposits of insecticides on filter paper against mature larvae of Dioryctria abietella. The insects were exposed for 30 minutes to deposits obtained by holding the filter papers in 0.25 and 2 percent emulsions for 30 seconds, followed by a 24-hour drying period. The materials tested were gamma isomer BHC, DDT, chlordane, toxophene, Sevin, and malathion; gamma isomer BHC gave the best control.

Cole (1958) of Gair Woodlands Corporation, working in cooperation with Southeastern Forest Experiment Station, sprayed seed production area in the early spring and the early summer of 1957 and 1958. He used an aerial spray of 12 ounces of 36 percent gamma isomer BHC in 1 gallon of oil per acre. Cone losses on the sprayed area were "significantly" less than losses on nearby unsprayed areas.

RESEARCH NEEDS

What studies are needed to round out knowledge of cone and seed insects? Here we consider in a general way the course of the work necessary to move toward solution of the various problems. Detailed plans will be drawn up for each of the separate studies as they are undertaken.

IDENTITY AND ROLE

Many of the uncertainties as to the identity and role of these insects can be cleared up by direct observations or relatively simple experiments. Periodic dissections and examinations of infested cones, particularly in spring and early summer, may yield some of the desired information in one or two years.

Rearing techniques will require special effort. Since most of the insects are present in the cones as immature forms which are difficult to identify, adult specimens must be reared and sent to specialists for identification. Until now no specialized rearing techniques have been used to obtain insect specimens from infested Douglas-fir cones. Insects reared from infested Douglas-fir cones have usually been obtained by placing mature cones in a box or cage and collecting the insects that emerge. Very little research has been done to investigate insects that may damage or destroy very young Douglas-fir cones and staminate flowers. Rearing methods should be developed to obtain adult specimens of these insects as well as those

whose larvae are prevalent in mature cones. This is likely to be a time-consuming process since the various insects in the cones may require different conditions to complete development, and some of them may have exacting ecological requirements.

There is a possibility that insects will destroy seed in storage. However none of the insects which attack the growing cones or developing seeds continue to feed on the seeds after they ripen. The insects which may attack tree seed in storage are likely to be well known stored-products pests, for which control recommendations are available, so little or no work will be required on this aspect of the problem.

There is still some uncertainty about the exact role of the insects reported to cause serious damage to Douglas-fir cones. Furthermore, there is a good possibility that some damaging species, particularly those that attack very small cones or staminate flowers, have been overlooked in previous investigations. Likewise, some insects now considered of minor importance may cause more damage than is suspected. Contarinia oregonensis is a good example. Only recently did close investigation reveal the great potential destructiveness of this midge.

Since information on the identity and roles of the insects in Douglas-fir cones is basic to solution of the insect problems, and since this type of information is relatively easy to obtain by direct observations or through simple experiments, every effort should be made to develop improved rearing and dissection methods.

BIOLOGICAL AND ECOLOGICAL RELATIONSHIPS

The application or integration of chemical, cultural, and biological control depends on a thorough understanding of the environmental factors which influence the insect population. Experiments to obtain these data will be relatively difficult and complicated. Like studies of identity and role, they will require better rearing techniques. Also more ecological data will be needed before biological experiments can be started. Although past work has provided a good background on the biological and ecological relationships of the four recognized insect pests in Douglas-fir cones, many details of these relationships are poorly understood.

Life Histories

Life history details that need emphasis include the time of occurrence of the different life stages, and the variations from the normal life cycle which enable the insects to perpetuate themselves when cone crops fail. Particularly pressing is the need for data by which the oviposition periods of the insects can be associated with some readily observable event in the annual phenological sequence.

The life cycle of Barbara colfaxiana is quite well known except for such details. But the life cycle of Dioryctria abietella, which appears to be quite variable, has not been well studied in California. Most of the detailed work on the life history of Megastigmus spermotrophus has been done in Europe. This work is well documented, but some local observations should be made to check the applicability of the European data. The general life history of Contarinia oregonensis is known, but the details and exact timing of events in the California species remains to be learned.

Insects now listed as of minor or undetermined importance must not be neglected. Knowledge of their life histories should be accumulated soon. If their roles prove more destructive than is suspected, or if they suddenly become more numerous, it will be difficult to devise effective control measures in time to keep damage at low levels.

Habits

The most notable gaps in biological knowledge of cone and seed insects are the habits of adults and young larvae. A method for predicting, preferably several weeks in advance, the time of adult emergence and start of oviposition is needed for the proper timing of spray applications. But neither flight habits, searching ability, reproductive capacity, nor longevity of the adults are known for any of the four major species. Foresters planning seed production areas should know if the insects fly long distances from infested areas and if they are able to search out cone-bearing trees. Perhaps these questions can be answered by applying recently developed methods for marking and recovering living insects. The longevity and reproductive capacity of the adult insects, which are important factors in the population dynamics of the insects, can be determined by relatively simple observations.

For the gall midges, Contarinia spp., which attack the cones two particular needs are : more definite data on the time when the mature larvae leave the cones, and data on larval activity between the time they leave the cones and when they spin cocoons. These larvae might be susceptible to cultural or biological control at the time they leave the cones or while they are in the duff. More observations are also needed on the duration of the oviposition period and adult life span.

Another point which should be studied is the fact that a significant percentage of the pupae of Barbara colfaxiana and the mature larvae of Megastigmus spermotrophus do not transform to adults after their first winter but wait two or three years before becoming adults. This may also be true of the other species of cone and seed insects although it has not been reported as yet.

Interrelationships

A problem largely neglected by past research is the interrelationship between different insects found in the cones. In general, the production of cones by trees is independent of the insect population and is also extremely variable. Frequently, a cone crop is attacked by more insects than the cones can support. Theoretically, intense competition for food would result in the survival of one insect species at the expense of the others. The degree to which this concept applies with cone and seed insects is an open question. Preliminary observations in northern California indicate that when the insect population is high and the cone supply is low, *Barbara colfaxiana* is the most successful competitor; a large population of this species survives and other species are suppressed. Perhaps the four insect species which regularly cause serious damage to the Douglas-fir cones and seeds normally suppress the species which are considered unimportant. This question could be resolved experimentally by eliminating a single species of insect from small groups of cones and observing the effect on the populations of the other species present.

Biotic Factors

Only the most rudimentary information is available for the known parasites and predators. The time when the parasites attack their hosts should be determined so that spraying can be scheduled to minimize the harm to beneficial insects. The ecology and life histories of the parasites and predators should be studied to determine if any of them might be used to control the insects which damage the cones. Although none of the parasites or predators has been reported to be effective control agents, it is fairly certain that one or more of them will reduce the population of cone moths substantially under the proper conditions. Disease organisms are not considered likely to control *Barbara colfaxiana* and *Megastigmus spermotrophus*, which pass almost their entire life cycle inside a cone or seed. However, the larvae of *Dioryctria abietella*, which feed in less protected situations and leave the cone to pupate, might be susceptible to control by pathogens. The larvae of *Contarinia oregonensis* which spend the winter in the duff would be especially likely to suffer from pathogens, particularly fungi. *Megastigmus spermotrophus* may be exposed to the depredations of seed-eating rodents. Birds and animals may seek out and eat the overwintering forms of the other cone and seed insects.

Climatic Factors

Climatic factors are known to exert a powerful influence on the activities and well-being of insects, and difficulties encountered in our preliminary rearing experiments suggest that cone and seed insects have exacting ecological requirements. A thorough knowledge of the effect of various climatic factors, such as temperature and rainfall,

on cone and seed insects, would be helpful in the formulation and application of control measures. Certain combinations of climatic conditions may prove to be unfavorable to these insects. In this event, seed-production areas could be established in areas having unfavorable climate, or perhaps the local climate could be altered in such a way as to be unfavorable. Radcliffe (1951) found that Barbara colfaxiana pupae overwintering on moist sites had a higher rate of extended diapause than those on dry sites. The climatic factors which affect this phenomenon should be investigated in the hope that they might be advantageously manipulated in seed-production areas.

Host Specificity

It would be dangerous to assume that the insects which attack the cones of Douglas-fir do not feed on the cones of other trees. Dioryctria abietella is known to have a wide range of hosts and feeding habits, but the host specificity of most of the other species of insects infesting Douglas-fir cones has not been closely studied. If any of the insects feed on trees other than Douglas-fir, sampling methods and control measures which take this factor into account must be developed.

An insect which feeds on several host trees would be less dependent on the supply of Douglas-fir cones and would be better able to maintain a population during periods when Douglas-fir cones are scarce. One way to test host specificity would be to cage mated females of important insects reared from Douglas-fir with the cones of other conifers to see if they will deposit eggs and if the larvae will grow to maturity.

Systematic investigation of the variations in susceptibility of individual Douglas-fir trees to attack by cone and seed insects, with the intention of propagating resistant trees as a seed source, would be a complicated long-term project. Nevertheless it would be well to start watching for trees which show signs of resistance and recording their locations.

SAMPLING METHODS

Good sampling methods are, of necessity, based on a thorough knowledge of the habits and life histories of the insect involved. Although detailed information on this subject is not now available, the development of sampling methods need not wait. Sampling studies can be undertaken on the basis of present knowledge of the insects, and modified as more accurate information is obtained. In this way a sampling method of limited reliability can be gradually refined and improved until the desired degree of reliability is attained.

So far damage estimates have been based entirely on the percent of cones or seeds infested. A better system would estimate not only the damage but also the number of insects. It would be still better if insect numbers could be estimated early in the summer and used to predict the amount of damage to be expected.

An estimate of this type might be based on the number of eggs or small larvae present in the cones early in the season, or on the numbers of adults taken in a trap during the oviposition period. Dissection methods suitable for detecting eggs or small larvae in the cones should not be too difficult to devise. Some of the types of traps which have been used in research on other insects are likely to work with cone and seed insects. For example, many species of moths and midges are readily caught in light traps. A good method of trapping adult cone and seed insects would also be useful for timing spray applications or detecting the insects at low population levels. Research on the habits of the insects will yield related data on the survival rates and amount of damage to be expected.

CONTROL METHODS

The ultimate control system for cone and seed insects is more likely to be a combination of insecticide applications and cultural or biological control methods than any one method alone. Since it is not possible to predict the effectiveness of any one method or combination, it is advisable to test and evaluate as many as possible.

Testing of cultural and biological control measures should be started as soon as biological and ecological investigations indicate what measures are likely to be effective. Screening of insecticides should be started when the proper time of application has been determined or when methods of rearing the insects in the laboratory have been found. The results of screening and laboratory tests will indicate which insecticides should be used in larger-scale pilot tests. The pilot tests should be designed to find the most economical method of control.

In past studies, DDT has been tested twice against the insect complex attacking Douglas-fir cones; nine other materials have been tested once. Many good insecticides have not yet been tested. Furthermore it seems ill-advised to eliminate any of the insecticides tested because they failed to give satisfactory control in one test. Additional small-scale tests should be made of chemicals known to be effective against insects which feed in sheltered situations or to have such desirable properties as systemic activity or long residual toxicity. Various types of formulations and methods of application should be tested.

Several research groups are experimenting with the use of fertilizers to increase seed production. Because fertilizers may affect

the insect population either favorably or unfavorably, it may be advisable to test mixtures of insecticides and fertilizers. A mixture might be especially effective against those cone and seed insects which spend part of their life cycle on the ground.

Biological and cultural control methods should be compared, in cost and effectiveness, with the corresponding qualities of chemical control to help determine what the ultimate control practices will be.

It may be possible to develop workable insecticidal control practices within 3 to 5 years after we have the necessary biological and ecological information. Control and biological methods will probably require a somewhat longer time for formulation, but these methods should not be neglected. In the long run, they are likely to be more economical and less troublesome than chemical control.

PRIORITIES

Studies which should be undertaken in Douglas-fir cone and seed insect research fall into three priority groups. In general, the priorities indicate the order of study, but certain preliminary work on subjects in a lower priority group can proceed concurrently with higher priority studies. The priorities have been assigned to broad topics of research. In practice these topics will be further divided on the basis of the insect species. An effort will be made at this level to avoid concentrating efforts or duplicating research on subjects that are already being investigated by another agency. Work on a narrow topic, for example the habits of *Barbara colfaxiana*, will be directed at filling the gaps in existing information rather than confirming the results of past work.

Priority 1: studies on the identity, life history, habits and ecology of the insects.--Studies on these subjects should receive the highest priority because the execution of the other phases of the project depend on this information. These studies should include rearings and dissection to determine what insects are present and what type of damage they cause; observations on the life history, habits, and interrelationship of the insects; and the effect of ecological factors on the insect population.

Priority 2: sampling methods.--Work on this subject is to some extent dependent on the data obtained from studies on the habits and life history of the insects. However, some of the work on sampling methods can be done concurrently with the studies in priority one. In fact some of the data for the investigations listed under priority one are obtained by sampling. Sampling methods will be needed to detect the insects at oviposition time, to assess the effect of control measures, and to predict population trends.

Priority 3: control methods.--Although immediate action on this subject seems desirable, well grounded research cannot be done until reliable data have been gathered on the identity and habits of the insects and good sampling methods have been developed. The habits and ecology of the insects should be studied for possible clues to possible cultural control methods. The possibility of controlling the insects through the use of parasites, predators, or diseases should be considered, insecticides should be tested for effectiveness against the insects.

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APPENDIX

Table 1.--Insects known or suspected to be destructive to cones and seeds of Douglas-fir

Name	Habits	Principal source of data
LEPIDOPTERA		
Barbara colfaxiana (Kearf.)	Larvae feed in cones	Cooley (1908) Hedlin (1958) Miller and Patterson (1916) Radcliffe (1951)
Dioryctria abietella (D. & S.)	Larvae feed in cones of Douglas-fir and many other conifers	Keen (1958) McKay (1943)
Henricus fuscodorsana (Kearf.)	Larvae feed in cones	Ross (Keen, 1958)
Eupithecia albicapitata (Packard)	Larvae feed in cones	Ross (Keen, 1958)
Eupithecia spermaphaga (Dyar)	Larvae feed in cones	Keen (1958)
Holcocera augusti Heinrich	Larvae feed in cones, possibly a scavenger	Keen (1958)
Holcocera sp.	Larvae feed in cones, possibly a scavenger	Keen (1958)
Laspeyresia bracteatana (Fern.)	Larvae bore through cones and feed on seeds; common in cones of true firs; rare in Douglas-fir cones	Keen (1958)
Laspeyresia sp.	Not described	Keen (1958)

Table 1.--Insects known or suspected to be destructive to cones and seeds of Douglas-fir, continued

Name	Habits	Principal source of data
Polychrosis piceana Freeman	Uncertain	Ross (Keen, 1958)
Chionodes periculella Bisck.	Believed to be scavengers	Keen (1958)
DIPTERA		
Earomyia barbara McAlipine	Larvae feed in cones	Keen (1958)
Earomyia aquilonia McAlipine	Larvae feed in cones	Keen (1958)
Contarinia oregonensis Foote	Larvae feed in cones forming galls which prevent seed extraction	Johnson and Heikkenen (1958)
Rubsaamenia keeni Foote	Larvae feed between cone scales	Keen (1958)
HYMENOPTERA		
Megastigmus spermotrophus Wachtl	Each larva feeds in a single seed	MacDougal(1906) Milliron (1949) Hussey (1954)
COLEOPTERA		
Ernobius melanoventris Ruckes	Larvae feed in cones	Ruckes[1/]
Ernobius punctulatus (Lec.)	Larvae feed on dead cones	Keen (1958)
Ernobius socialis Fall	Larvae feed in cones after maturity	Koerber[2/]
Ernobius sp.	Uncertain	Keen (1958)

Table 1.--Insects known or suspected to be destructive to cones and seeds of Douglas-fir, continued

Name	Habits	Principal source of data
HEMIPTERA		
Leptoglossus occidentalis	Nymphs and adults feed on cones and seeds	Koerber[2]
Gastrodes pacificus (Provancher)	Adults feed on seeds	Koerber[2]

1/ Personal communication.

2/ From data gathered by the author in the course of preliminary work on this project.

Table 2.--Insects found in Douglas-fir cones whose role is uncertain

COLEOPTERA	
	Anthicus nitidulus (Lec.)
	Notoxus constrictus Casey
	Cleis picta var. *contexta* Muls.
	Hippodamia convergens Guer.
	Psyllobora viginti-maculata var. *taedata* Lec.
	Henoticus californicus (Mann.)
	Dirotognathus sp.
	Corticaria sp.
DIPTERA	
	Bradysia pauciseta (Felt)
	Lestodiplosis taxiconis Foote
	Mycodiplosis coryloides Foote
HYMENOPTERA	
	Eurytoma sp.

Table 3.--Parasites and predators attacking Douglas-fir cone and seed insects

Name	Taxonomic determination	Host	Source of biological data
COLEOPTERA			
Enoclerus humeralis Schaeffer	USNM, Fisher	B. colfaxiana and probably others	Keen (1958)
Cymatodera ovipennis Lec.	USNM, Fisher	Uncertain	Keen (1958)
DIPTERA			
Lydellohoughia sp.	USNM, Sabrosky	Uncertain	Keen (1958)
Unidentified Larvaevorid	Koerber	B. colfaxiana	Koerber 1/
HYMENOPTERA			
Bethylidae			
Goniozus longinervis Fouts	USNM, Krombein	B. colfaxiana	Koerber 1/
Perisierola sp.	USNM	Uncertain	Keen (1958)
Braconidae			
Apanteles petrovae Walley	USNM, Muesebeck	B. Colfaxiana	Koerber 1/
Apanteles sp.	USNM, Rohwer	Uncertain	Keen (1958)
Aphidius bifasciatus Ashm.	USNM, Muesebeck	Probably aphids	Keen (1958)
Blacus sp.	USNM, Rohwer	Uncertain	Keen (1958)
Bracon erucarum (Cushm.)	USNM, Muesebeck	Probably B. colfaxiana	Keen (1958)
Bracon rhyacioniae (Mues.)	USNM, Muesebeck	B. colfaxiana or D. abietella	Keen (1958)
Bracon xanthonotus Ashm.	USNM, Muesebeck	Uncertain	Keen (1958)
Bracon n. sp.	USNM, Rohwer	Uncertain	Keen (1958)
Rogas autographae Vier.	USNM, Muesebeck	Uncertain	Koerber 1/
Neoblacus rufipes Ashm.	USNM, Muesebeck	Uncertain	Koerber 1/
Eubadizon definitum Mues.	USNM, Muesebeck	Uncertain	Koerber 1/
Eubadizon sp.	USNM, Muesebeck	Uncertain	Keen (1958)
Ichneumonidae			
Calliephialtes comstockii (Cresson)	USNM, Walkley	B. Colfaxiana	Keen (1958)
Campoplex conocola (Rhower)	USNM, Rohwer	Probably D. abietella	Keen (1958)
Dicaelotus sp.	USNM, Walkley	Uncertain	Keen (1958)
Exochus evetriae (Rohwer)	USNM, Sargent	B. colfaxiana	Keen (1958)
Glypta evetriae Cushm.	USNM, Walkley	B. colfaxiana	Keen (1958)
Glypta sp.	USNM, Walkley	Uncertain	Koerber 1/
Itoplectis evetriae Vier.	USNM, Rohwer	B. colfaxiana	Keen (1958)

Table 3.--Parasites and predators attacking Douglas-fir cone and seed insects, continued

Name	Taxonomic determination	Host	Source biological data
Phaeogenes sp.	USNM, Rohwer	Uncertain	Keen (1958)
Pimplopterus conocola (Rohwer)	USNM, Walkley	*B. colfaxiana*	Keen (1958)
Pimplopterus evetriae (Rohwer)	USNM, Rohwer	*B. colfaxiana*	Keen (1958)
Eulophidae			
Aprostocetus sp.	Unknown	Uncertain	Keen (1958)
Elachertus proteateratus (How.)	USNM, Burks	Uncertain	Koerber 1/
Elachertus sp.	Unknown	Uncertain	Keen (1958)
Hyssopus evetriae (Girault)	USNM, Burks	*B. colfaxiana*	Keen (1958)
Tetrastichus strobilus Burks	USNM, Burks	Uncertain	Patterson (Keen 1958)
Tetrastichus coerulescens Ashm.	USNM, Burks	*Elacheratus* sp.	Koerber 1/
Tetrastichus sp.	USNM, Burks	Uncertain	Keen (1958)
Horismenus sp.	USNM, Burks	Uncertain	Koerber 1/
Eupelmidae			
Eupelmus brevicauda (Crawford)	USNM, Burks	Uncertain	Koerber 1/
Eupelmus sp.	USNM, Burks	Uncertain	Keen (1958)
Perilampidae			
Perilampus fulvicornis Ashm.	USNM, Burks	Uncertain	Koerber 1/
Pteromalidae			
Amblymerus apicalis Thomson	Kerrich	*M. spermotrophus*	Hussey (1955)
Amblymerus verditer (Norton)	Muesebeck	*B. colfaxiana*	Muesebeck (1951)
Amblymerus sp.	USNM, Burks	Uncertain	Keen (1958)
Anogmus strobilorum Thomson	Kerrich	*M. spermotrophus*	Hussey (1955)
Trichomalus sp.	Kerrich	*M. spermotrophus*	Hussey (1955)
Dibrachys cavus (Walk.)	USNM, Burks	Uncertain	Koerber 1/
Zacalochlora milleri Crawford	USNM, Rohwer	*Laspeyresia* sp.	Keen (1958)
Homoporus sp.	USNM, Burks	Uncertain	Koerber 1/
Platygasteridae			
Platygaster n. sp.	USNM, Muesebeck	Uncertain	Koerber 1/
Torymidae			
Torymus sp.	USNM, Burks	*Contarinia* sp.	Koerber 1/
Trichogrammatidae			
Trichogramma minutum Riley	USNM, Burks	*B. colfaxiana*	Koerber 1/
Ufens sp.	USNM, Burks	*B. colfaxiana*	Koerber 1/

1/ From data gathered by the author in the course of preliminary work on this project.

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